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MEASUREMENTS OF LOW-ENERGY PARTICLES BY THE "MARS-2" AND "MARS-3" PLANETARY PROBES

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16. Abstract

An instrument is described which measures electrons and ions in the 0.03 to 10 kev energy range. Two such instruments were installed in the "Mars-2" and "Mars-3" planetary probes. With the device, based on the principle of an electrostatic analyzer with a detector, energy spectra are measured by sequential volt switching through the analyzer channels, each of the 8 channels performing in its energy range. These instruments operate in three modes differing in frequency and number of measurements. In one of the modes, with the instruments operating continuously and taking spectra every two minutes, it was possible to determine the topography and boundaries of the interaction zone between the solar wind and Mars with high accuracy.

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MEASUREMENTS OF LOW-ENERGY PARTICLES BY THE "MARS-2" AND "MARS-3" PLANETARY PROBES

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1. Instrumentation and Measurement Technique /738*

Measurement of low-energy particles (electrons, ions, and neutral atoms) was performed on the "Mars-2" and "Mars-3" planetary probes with the RIEP-2801 spectrometer, which is constructed on the principle of an electrostatic analyzer (EA) with a detector, an electron channel multiplier (ECM) operating in the counting mode with the output data fed to analog telemetry.

Description of Instruments

The RIEP-2801 instrument mounted on the "Mars-3" planetary probe included eight identical detection units (DU), each of which embodies a cylindrical EA, an ECM, a charge-sensitive amplifier, and a pulse shaper. Paraphase voltage was applied to the electrostatic analyzers (deflection angle 100°, $R_{max} = 41 \pm 0.03$ mm, $R_{min} = 39 \pm 0.03$ mm). ECMs representing a bent flattened tube of specially treated glass were selected as the particle detectors because of their high technical qualities, economy, and small dimensions and weight. The incorporation of a pulse shaper-amplifier in the DU makes it possible to reduce possible interference in the circuits.

The use of these detection units (Figure 1) made it possible to build the instrument on the modular principle. In addition, it is possible simultaneously to measure particle fluxes in different energy intervals and to detect rapid variations in them in time and space.

Depending on the polarity of the potentials applied to the analyzer plates and to the ECM output, the detection units were used for analysis of both positively and negatively charged particles. In electron recording in the

*Numbers in the margin indicate pagination in the foreign text.

detection units a positive bias of +0.2 kv was applied to the multiplier input, and the ECM output and anode were connected to a power supply source of a /739 voltage of +3.6 kv. In the mode for recording of positively charged particles in the detection units the ECM output and anode were connected through resistors to the housing, and a voltage of -3.6 kv, which at the same time is accelerating voltage for postively charged particles, was applied to the ECM input. As a result, the effectiveness of ion recording by the multiplier depended very slightly on the energy in the energy range selected for measurements.

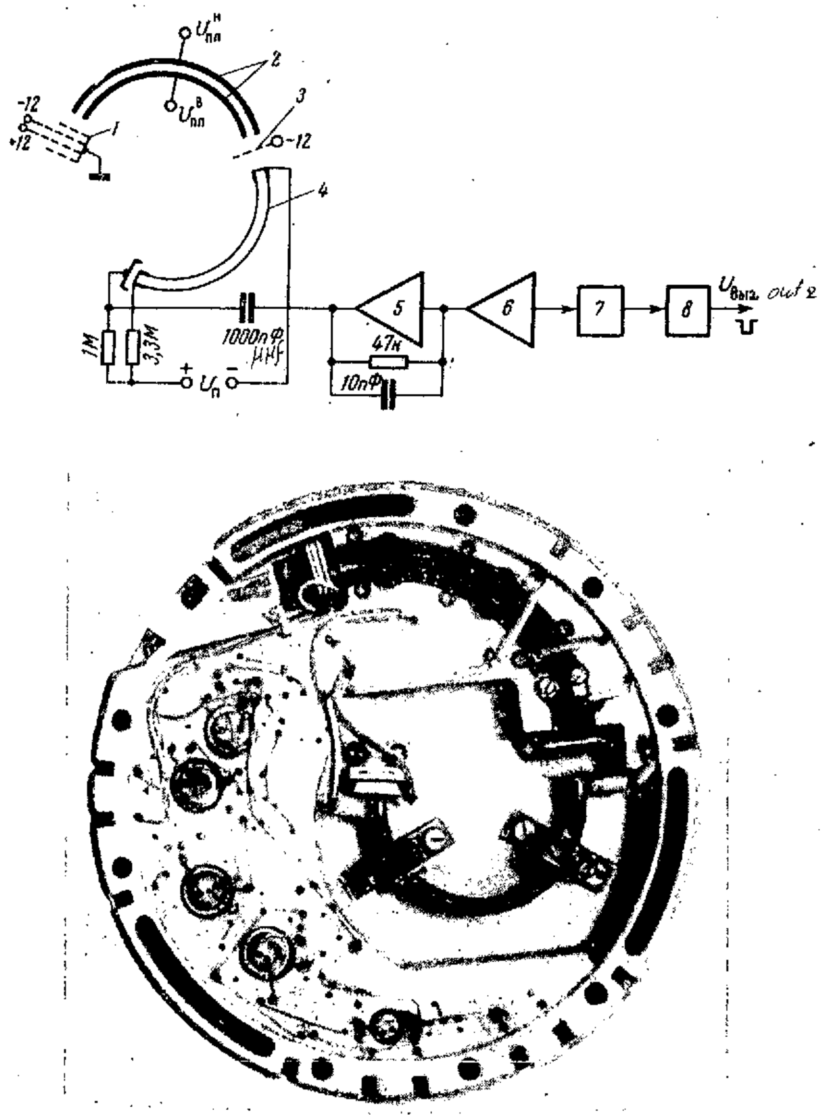

Figure 1. Detection Unit
Top, Structural diagram: 1, Input grid unit; 2, Analyzer; 3, Reflector grid; 4, ECM; 5, Charge-sensitive preamplifier; 6, Amplifier; 7, Discriminator; 8, Shaper. Bottom, Overall View.

Measurement of the spectral distributions of particles was conducted by applying to the analyzer plates four increasing voltage stages the values of which were approximately 0.18 U_{max}; approximately 0.36 U_{max}; 0.5 U_{max} and U_{max}. The energy range distribution obtained is illustrated in Figure 2. For the purpose of comparison of readings and determination of the relative effectiveness of recording by the detection units in processing of measurement results the energy values over the entire energy interval of the spectrometers were selected /740 so that the energy zones of adjacent detector units overlapped and so that approximately uniform distribution of the measured points over the energy scale in the logarithmic scale was simultaneously assurred.

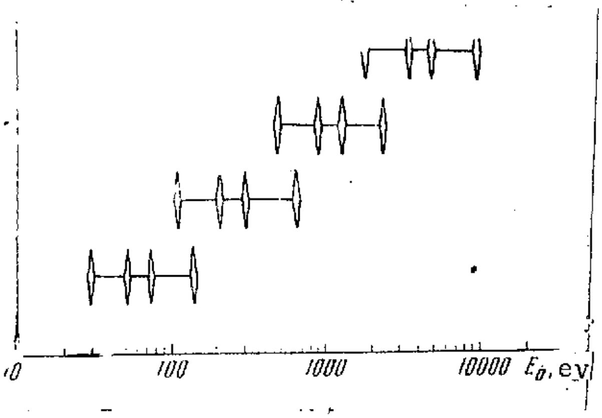

Figure 2. Distribution of Energy Ranges of Instrument.

In the spectrometer installed on the "Mars-2" planetary probe four detection units were used to record the electron flux and four for ions in identical energy ranges of 0.03 to 10 kev. The maximum energy values of the particles recorded, E_0, wich corresponds to the centers of the particle transmission zones of the analyzer, were 10; 2.5; 0.67; and 0.14 kev. Because of the particle recording efficiency, the transmission factor of the analyzing system, and the signal frequency of (2 to $2 \cdot 10^4$) pulse/sec recorded by the measuring circuits, the instrument provided for measurement of particle flux densities in the range of (10^5 to 10^9) particles/ /sec$\cdot$cm$^2\cdot$ster. A detailed description of the structural diagram of the instrument and its characteristics is given in [1, 2].

The modular layout of the instrument made it fairly simple to modify the number of detection units allocated for recording of a particular type of particle. Thus it was believed advisable for the "Mars-3" planetary probe to replace the electron recording channels with maximum measured particle energies of 10 and 2.5 kev by channels permitting measurement of neutral atom fluxes. For this purpose ultrathin 150 Å carbon sheets were installed in two detection units, and the detection units themselves were connected in the recording circuit for positively charged particles with maximum energy values of 10 and 2.5 kev. Thus, if only the flux of charged particles is recorded at the analyzer output and if the characteristics of the sheet are known, it is possible to determine the flux density and energy distribution of neutral atoms if their fluxes are sufficiently large. Since no charged particle selectors were installed in front of the carbon sheet aperture, as was done in [3], solar wind ions also entered the entrance aperture of the analyzer with the carbon sheet. Hence the recording threshold of the neutral atom flux depended on the total ion flow recorded by the instrument in a particular energy interval. The most favorable situation for measurement of the neutral atom flux is a small flux of ions entering the detector. The contribution of the neutral component to the total particle flux can be determined from the readings of adjacent detection units with and without the carbon sheet.

Since it was planned to conduct measurements of the particle flux both in the vicinity of Mars and along the path from Earth to Mars, particular attention in development of the instrument was devoted to determination of the safe life of the ECM, relative measurements of the recording efficiency of the ECM, and verification of the servicability of the instrument in flight. The ECM design selected for the spectrometer, in the form of a flattened curved tube of constant cross-section over a length of 2×6 mm^2, possesses a sufficiently long safe life, measured frequency range, and stability. An ECM with an amplification factor of $(1.5 \text{ to } 8) \cdot 10^7$ was selected for installation in the instrument.

In order to determine the stability of the ECM amplification factor toward the integral load, study was made of the variation in the amplification factor, recording efficiency, and the amplitude distribution form with several sample multipliers from the same batch installed in the instruments designed for the flight [4]. Measurements were conducted with electron beams at a pressure of 10^{-6} mm Hg over a prolonged period of time. /741

Appreciable decrease in the amplification of the multipliers used occurs after $Q_{out} = 5 \cdot 10^{-3}$ C, and the value of $(2 \text{ to } 3) \cdot 10^{-2}$ C is the limiting value for the type of ECM employed and the signal recording threshold established.

In view of the dispersion of the amplification factor of the ECM the number of pulses which can be counted by the multipliers ranges from $5 \cdot 10^9$ to $3 \cdot 10^{10}$ pulses.

The absolute sensitivity of a spectrometer to electrons, and their angular and energy characteristics (Figure 3), were determined on the basis of a tritium reference source. The ion channels were checked with ion beams from a stable ion source with ionization of the gas by an electron beam.

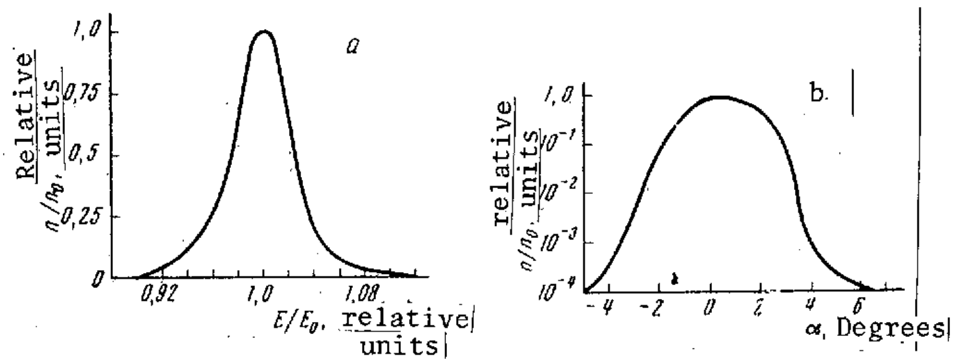

Figure 3. Detection Unit Characteristics Measured With Wide Unidirectional Particle Beam.
a, Energy; b, Angular.

To verify the stability of the logarithmic intensimeters and eliminate possible errors arising on change in the characteristics of this unit, a stable frequency generator emitting pulses with two stable repetition rates was introduced into the spectrometer. This mode was switched on once every 24 hours during flight.

Immediately after the probes had been set in the path from Earth toward Mars they were oriented so that the axis coinciding with the visual axis of the instrument was oriented towards the Sun. There was a certain amount of rotation about this axis at low angular velocity.

The second mode of orientation with stabilization not of one but of all axes was switched on prior to approach toward Mars and was continued, except for brief interruptions, throughout the time of flight of the probe in the orbit of the Mars satellite.

These two modes made it possible to conduct solar wind measurements along the entire path of the flight and in the orbit of Mars. The instrument recorded particle fluxes in its angle of vision which were at least one to two orders higher than the instrument's threshold, virtually always along the flight path and almost all the time while in orbit. Thus use of the narrowly directed instrument in the oriented planetary probe made it possible dependably to record the velocity of the solar wind and to obtain estimates of the proton and α-particle temperatures and the relative α-particle concentration.

<u>Taking of Energy Spectra and Feeding of Signals to Telemetry</u> /742

An important question in the measurement method adopted is the procedure for taking the energy spectra. In this particular case, considering the characteristics of the instrument which had been developed, it was deemed convenient to make up the spectrum from partial subspectra taken by individual channels (see the foregoing). The advantage of the method selected, along with the shorter time required for taking one spectrum, is represented by the high dependability of the entire instrument. The failure of one or even two channels measuring particles of one type (electrons or ions) does not prevent continuation of the experiment, since the remaining channels record the spectrum, although in less detail. This is of particular importance in experiments requiring prolonged instrument servicability, as is the case in flights toward planets.

A disadvantage of the method adopted is represented by the possibility of change in the relative sensitivity of the detection units, but the procedure adopted for taking the spectrum, one involving overlapping of adjacent channels in the energy range, makes it possible to take this effect into account in processing of the data.

Throughout the flight the instruments installed on the "Mars-2" and "Mars-3" planetary probes operated in one of three possible modes: a) two independent energy spectra were taken consecutively for a period of a minute, with the instrument switched on once every 20 minutes; b) two spectra were taken for a period of a minute, with the instrument switched on once every 10 minutes; c) two consecutive spectra were taken for a period of a minute once every two minutes without the instrument being switched off.

In mode a) the instruments operated almost all the time during the flight from Earth toward Mars. Measurement mode b) was engaged almost all the time while in orbit around Mars. Mode c) was engaged in the most interesting circumstances, usually in the area of the orbit pericenter, as was the case with the sessions of 21 January and 6 and 18 April 1972. In this case mode c) made it possible to determine with the highest accuracy the topography and boundaries of the zones of interaction between the solar wind and Mars. It should be noted, however, that the array of instruments measuring the plasma and magnetic fields were often switched off in the region of the orbit nearest the planet and the instruments for measurement of the characteristics of the atmosphere and surface of the planet were switched on. In this particular experiment this prevented full determination of the inner boundary of the zone of interaction between the solar wind and Mars.

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